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A ground vibration test on the GARTEUR SM AG-19

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ABSTRACT
In april 1995 a Structures and Materials Action Group (SM AG-19) of GARTEUR (Group for Aeronautical Research and Technology in Europe) started an activity with the major objective to compare a number of current measurement and identification techniques applied to a common testbed. Twelve European groups participated, most of them involved in ground vibration testing aircraft for flutter clearance purposes.
It seldom occurs in practice that a ground vibration test is repeated by a third party and can therefore be considered as an unique opportunity to validate the results of each individual test setup.
This paper addresses the variability of the measured data and analysis results. Further this paper deals with the identification and comparison of the modal parameters of this testbed, where three closely spaced modes were incorporated as a "hidden" vibration problem

Contents

14 Figures

(11 pages in total)

A GROUND VIBRATION TEST ON THE GARTEUR TESTBED SM AG-19

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Abstract

In april 1995 a Structures and Materials Action Group (SM AG-19) of GARTEUR (Group for Aeronautical Research and Technology in Europe) started an activity with the major objective to compare a number of current measurement and identification techniques applied to a common testbed. Twelve European groups participated, most of them involved in ground vibration testing of aircraft for flutter clearance purposes.

It seldom occurs in practice that a ground vibration test is repeated by a third-party and can therefore be considered as an unique opportunity to validate the results of each individual test setup.

This paper addresses the variability of the measured data and analysis results. Further this paper deals with the identification and comparison of the modal parameters of this testbed, where three closely spaced modes were incorporated as a "hidden" vibration problem.

1. Introduction

In the certification process of new aircraft, a ground vibration test (GVT) plays an important role for the verification or updating of analytical models. Facing the risk of flutter, high quality GVT results has to be achieved to model the vibrational characteristics of an airplane structure being a basis for reliable flutter predictions.

In April 1995 an Action Group (SM AG-19) of GARTEUR started its activities with the major objective to compare a number of current measurement and identification techniques applied to a common testbed designed and manufactured by ONERA [Ref. 1]. The various companies, research centers and universities in Europe participating were ONERA, SOPEMEA, AEROSPATIALE, CNAM and INTESPACE from France, DLR from Germany, NLR and Fokker from the Netherlands, SAAB from Sweden and finally DRA, University of Manchester and the Imperial College from the United Kingdom.
More specifically, the objectives of the GVT tests were to evaluate the reliability of test methods and to compare modal parameters extracted from different identification techniques.

This paper deals with the identification of modal parameters of the testbed (Fig. 1) but does not intent to evaluate a specific test setup, data reduction or identification technique as there was a variety in test equipment and software used by the various participants.

2. Requirements and recommendations for the ground vibration test

The ground vibration test on the testbed aimed to measure transfer functions between the response of the structure and the applied excitation forces and to determine the natural frequencies and mode shapes with related parameters. Each participant was requested to provide at least (i) a reference set of four transfer functions corresponding to excitation and response of the left and right wingtip body, and (ii) the mode shapes of the testbed in a 4-65 Hz band. It was further agreed between the participants that the mode shapes would be based on 24 accelerometer positions (Fig. 2) recommended by ONERA. Attachment of two electrodynamic shakers was foreseen at position 12z and 112z (Fig. 2) close to additional wing tip masses of 200g each, which were installed to introduce a "hidden" vibration problem of three closely spaced natural frequencies with their mode shapes.

The aluminium testbed with dimensions of 2m (span) and 1,5m (length of fuselage) and a mass of 45 kg was suspended by a common set of bungees in order to obtain similar boundary conditions for each participant. The bungees were linked to a plate and the participants were free to fix this plate in any appropriate manner. To the participants it was further recommended to detect at least the highest rigid body frequency (the heave mode) and to measure the second mode shape of the testbed being the fuselage torsion mode (f = 16,17 Hz with a damping factor of 1,45 %) as a check of proper assembly of the testbed. Apart from that the participants were free to perform the ground vibration test following their own view and experiences to identify the vibration modes and the related modal parameters (frequencies, damping factors and modal mass).

3. Equipment setup

An interesting aspect in this GARTEUR activity was the use of different measuring equipment, data reduction- and analysis techniques by the various participants.
Besides commercially available equipment also "in-house made" equipment was used like accelerometers, conditioners or filters. Most of the participants used front-end type multi-channel measuring systems with software of different suppliers like CADA-X (Leuven Measurement Systems), the Structural Dynamics Toolbox for use with Matlab (Scientific Software Group) or "in-house made" software.

Excitation of the testbed was performed in various ways. The participants used different shaker positions but also mounting of the shakers was quite different (again Fig. 1). Most of the participants were able to use uncorrelated band limited noise showing the symmetrical and anti-symmetrical frequencies simultaneously in the transfer functions; otherwise correlated excitation signals were applied by which the shakers act in-phase or in counter- phase. The excitation forces were measured by load cells or by the current through the shakers. The latter procedure needed a compensation for the moving mass of the shakers because of the relative low mass of the testbed. A typical equipment setup of one of the participants for this testbed is presented in Figure 3.

4. The ground vibration test in practice

In spite of the recommendations and requirements for the ground vibration tests, given by ONERA, some "shortcomings" occurred in the test setup of various participants. Inappropriate mass compensation at the wingtips (to compensate for the moving mass of the shakers) was a major source, but also the position of the shakers at the wingtips as clearly shown in Figure 4. For that reason, ONERA was not able to include all data sets in one comparison but had to make a selection between two representative groups of participants [Ref. 1]. The final results however appeared to be consistent and differences in natural frequencies, especially in the 30-35 Hz band where the presence of mass is of a substantial influence on the three closely spaced modes (see section 5), could be easily explained. Finally the test setup of some participants suffered from suspension modes appearing in the transfer functions.

5. Presentation of some typical results

5.1 Transfer functions

Using uncorrelated noise as excitation of the testbed transfer functions like those presented in Figure 5 were obtained. These include both the symmetrical and antisymmetrical behaviour of the testbed. Observation shows that the natural frequencies around 35 Hz are sensitive for a different mass compensation (see Fig. 4b and Fig. 4d) resulting in a slight frequency shift. The 180 deg phase difference is explained by the way of mounting the loadcell (upside down, -z) by one of the participants.

The presence of closely spaced modes is well illustrated in Figure 6. When measuring the transfer between excitation and response on both wings (105z and 5z, Fig. 2) a single circle is the result showing no indication of a hidden vibration problem. By measuring the response on one of the wing tip bodies (12z) however, the closely spaced modes (as coupled circles) become visible (Fig. 6b).

5.2 Frequencies, damping factors and mode shapes

Analysis of the closely spaced modes took place in different ways depending of the software used by the participants. An example is shown in Figure 7.
Applying a multi degree of freedom curve fitter on the data and creating a stabilization diagram, the evaluation of frequency

and damping (poles) is shown with an increasing number of computational modes (up to 32). Once stabilized the poles are marked by "S" and the residuals are determined, resulting in a mode shape and presented in an animated display. The three closely spaced modes (Fig. 7) were identified as an antisymmetrical and symmetrical rotation of the wing tip bodies and a three node bending of the wing. The results fairly match the finite element analysis of the testbed (Fig. 8) performed by DLR (Germany) in an earlier stage to provide proper accelerometer positions and exciter locations for the ground vibration test [Ref. 2]. Finally a representative overview of all mode shapes measured in the 4-65 Hz band is presented in Figure 9.

5.3 Modal mass

It is well known that the modal (or generalized) mass is a relevant parameter in aeroelastic (flutter) prediction methods. An inaccurate determination of the modal mass may lead to unreliable computations on the flutter speed of an aircraft. This GARTEUR activity was an excellent opportunity to compare modal mass results determined by the participants (section 6). Also some checks on the data processing software were performed indicating the importance of an accurate measurement of damping factors and mode shapes.

A relatively simple check is the determination of the modal mass of the heave mode (f = 1,8 Hz) by which the testbed is considered to behave rigid in its suspension (Fig. 10a). In that case, the weight of the model (around 44,8 kg) should be equal to the computed modal mass. The data processing computing of one of the participants yielded results (Fig. 10b) in which the modal mass ranges from 45,2 kg (+ 1%) to 50,7 kg (+ 13%) depending of the damping. The same participant did a further check for the second mode shape of the model using the technique of added masses (Δm) by measuring the frequency shift (Δf) after re-adjusting the 90 deg phase criterion during a sine dwell. The result (Fig. 11) should be a straight line if the mode shape is not influenced by added masses placed at locations 112z and 12z. Comparable results with the computation (17,9 kg) are obtained (Fig. 12). The next section however will show that the modal mass determination still remains a subject of investigation because of its variability.

6. Comparison of results

Considerable effort was put into the comparison of test results of the various participants carried out by ONERA [Ref. 1] concerning natural frequencies and damping factors and by DLR [Ref. 2] concerning the modal mass. The results are presented in Figure 13 and Figure 14. Here the participants are identified as A to J in chronological order of testing. Figure 13a shows the variation of identified frequencies to be close to only 4%. The "discrepancies" can be easily related to inappropriate selection of compensation masses or shaker position. The unexpected variability of the first mode (wing bending) around f = 6.5 Hz could be possibly explained by interaction with the rigid heave mode which varied between 1.8 and 2.7 Hz as measured by various participants.

For the damping ratios (Fig. 13b), the variability is close to 30%. Modes 7 and 8 show the largest variation but have the lowest damping ratio (coplanar modes, 0.2% - 0.6%). This confirms the fact that lightly damped modes are difficult to characterize. The plots do not indicate any particular trend that would be characteristic for either the method of identification or force appropriation.

Finally the modal (or generalized) mass comparison is presented in Figure 14. The values calculated from mass normalized mode shapes show similar trends but scatter occurs at all modes. This fact confirms general experiences in determining the modal mass of a real aircraft. The modal mass computation for mode 3 and 4, being the closely spaced rotational wingtip body modes, shows the lowest values. It is however the opinion of the authors that the scatter of the data should be lesser for a rather linear structure like this testbed. Further investigation on modal mass measurement is therefore recommended.

7. Conclusions

- The present GARTEUR activity (SM AG-19) has clearly shown that different test setups and the variety in hard- and software applied by the various participants, have resulted in a consistent set of data.
- The technique of force measurements by load cells or by electrical current through a shaker showed similar transfer functions and led to comparable mode shape results.
- Analysis of the variability of the test results showed an amount of only 4% in natural frequencies and around 30% in damping factors.
- Variation in results of the natural frequencies could be easily traced back to "shortcomings" in the test setups as applied by the participants.
- The modal mass measurements showed similar trends but are affected by scatter of the data.
- The determination of the modal mass of this testbed requires therefore further investigation.
- The present activity has highlighted the reliability of the various test- and identification methods of this ground vibration test performed by the GARTEUR participants.

8. References

1. Balmès, E. "GARTEUR Group on Ground Vibration Testing. Results from the test of a single structure by 12 laboratories in Europe", paper presented at IMAC, Febr. 1997, USA.
2. Degener, M. "Ground Vibration tests on an Aircraft Model Performed as Part of a European Round Robin Exercise", paper presented at the International Forum on Aeroelasticity and Structural Dynamics, July 1997, Rome, Italy.

9. About GARTEUR

The Group for Aeronautical Research and Technology in Europe (GARTEUR) was formed in 1973 by representatives of the government departments responsible for aeronautical research in France, Germany and the United Kingdom. The Netherlands joined in 1977 and Sweden in 1992.

The aim of GARTEUR is, in the light of the needs of the European Aeronautical Industry, to strengthen collaboration in aeronautical research and technology between countries with major research and test capabilities and with government-funded programmes in this field.

The cooperation in GARTEUR is concentrated on pre-competitive aeronautical research. Potential research areas and subjects are identified by Groups of Responsables and investigated for collaboration feasibility by Exploratory Groups. If the subject is feasible, an Action Group is established.

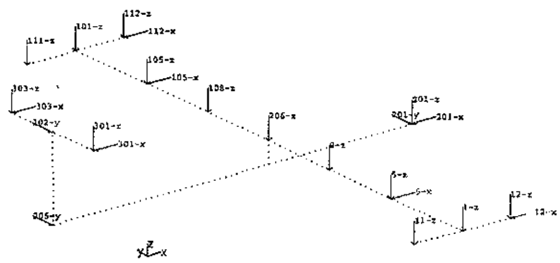
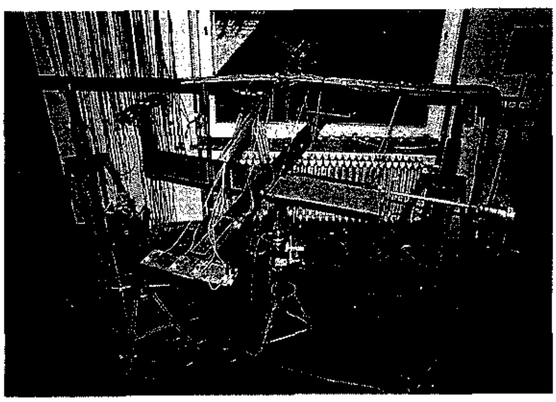
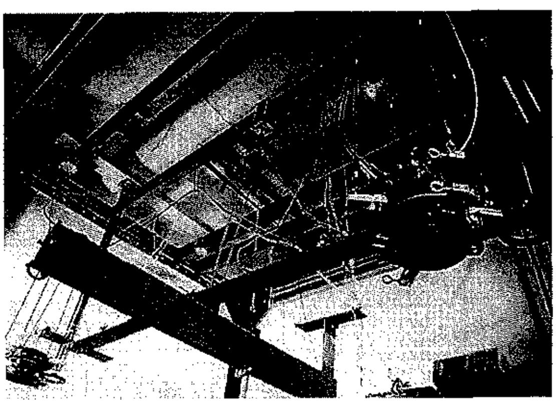


Fig. 2 The 24 accelerometer positions and directions



a) by DLR (Germany)



b) by CNAM (France)

Fig. 1 Variety in the test setup

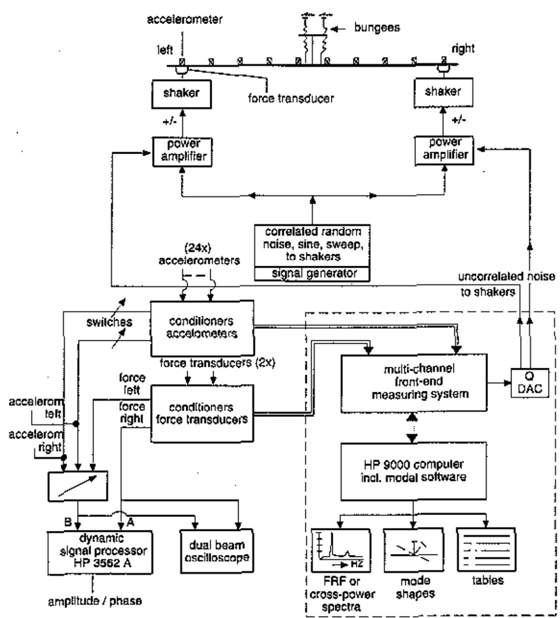
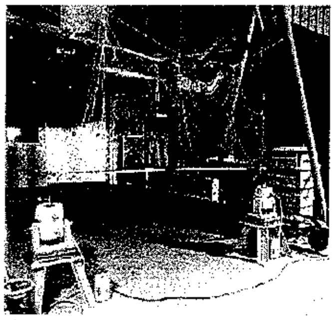
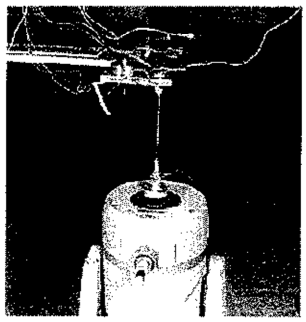


Fig. 3 Example of equipment setup

DRA/Univ. of Manchester

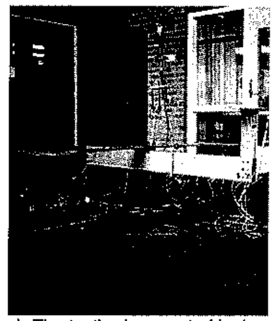


a) The overall test setup

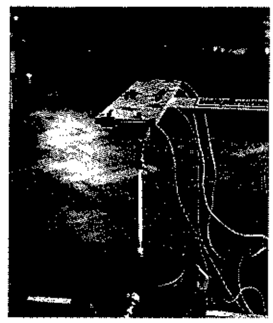


b) The force transducer position and attachment

NLR/Fokker

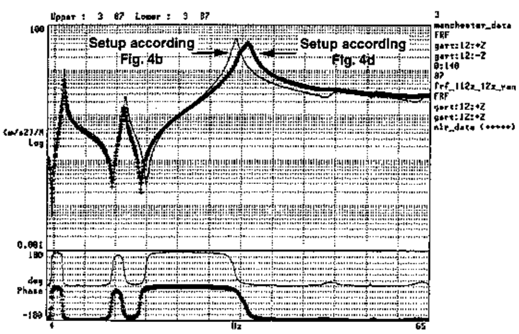


c) The testbed supported by bungees

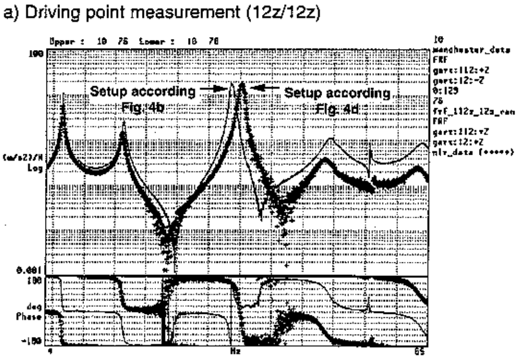


d) Shaker connection to the testbed

Fig. 4 Variety in mounting the shakers and compensation of tipmasses

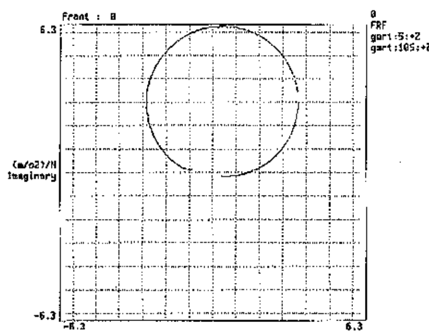


a) Driving point measurement (12z/12z)

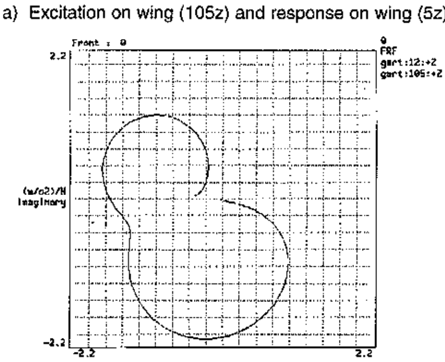


b) Cross transfer (112z/12z)

Fig. 5 Effect of tipmasses and shaker position on transfer functions



a) Excitation on wing (105z) and response on wing (5z)



b) Excitation on wing (105z) and response on wingtip body (12z)

Fig. 6 Nyquist diagrams in the 30-35 Hz band

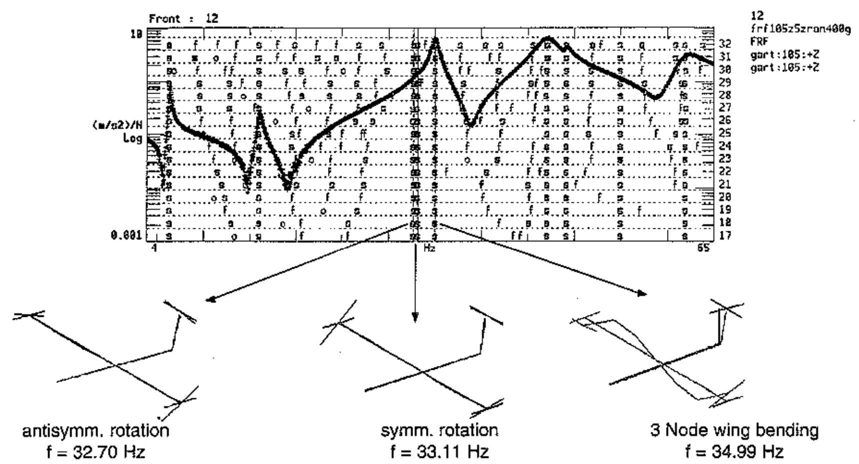


Fig. 7 The "hidden" vibration problem of three closely spaced modes

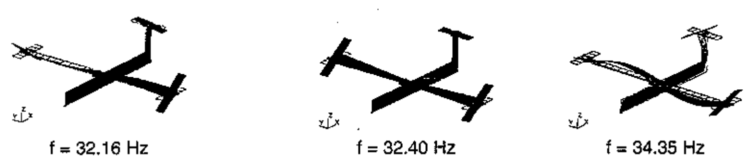


Fig. 8 The closely spaced modes from computations (including the masses of accelerometers) performed by DLR (from ref. 2)

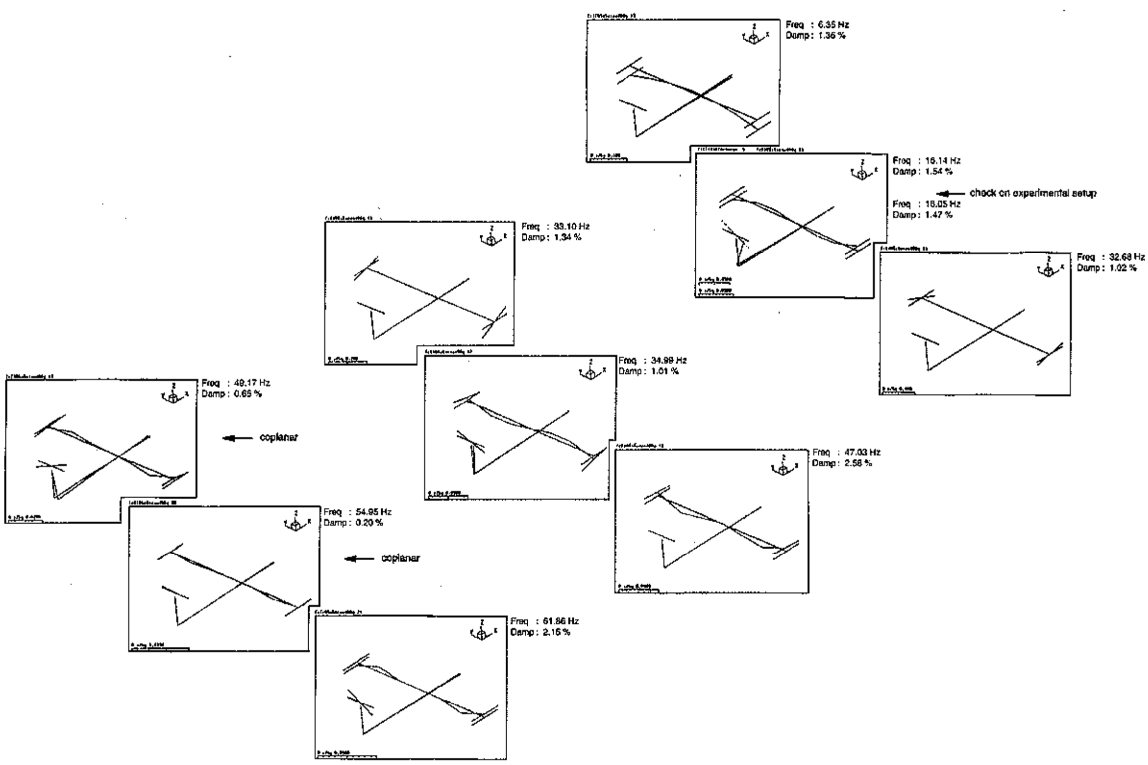
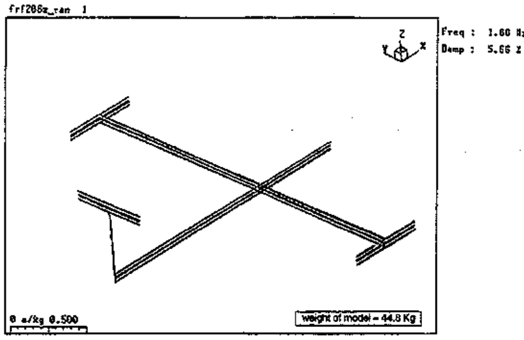


Fig. 9 The mode shapes of the testbed in the 4-65 Hz band as measured by one of the participants



a) Heave mode of the testbed

Generalized modal parameters when scaled as
UNITY COMPONENT for identifier "gart:206:+Z"

No	mode no	freq Hz	damping (%)	mass kg	damping kg/s	stiffness kg/s2
1	1	1.68	5.66	4.52e+01	6.05e+01	[illegible]
2	2	1.84	[illegible]	5.07e+01	5.54e+01	6.76e+03

b) Computation of the modal mass

Fig. 10 The modal mass of the heave mode

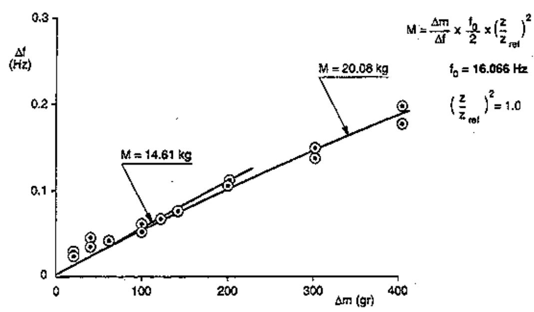
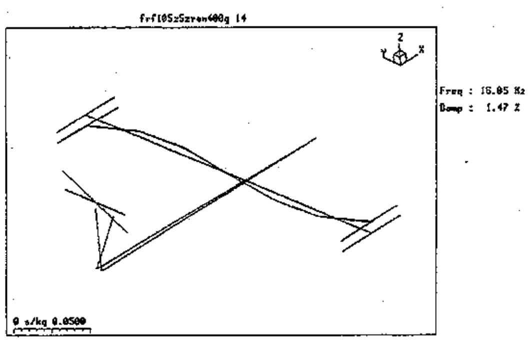


Fig. 11 Determination of modal mass of the fuselage torsion mode (pos.: 112z/12z) by added masses at a sine dwell



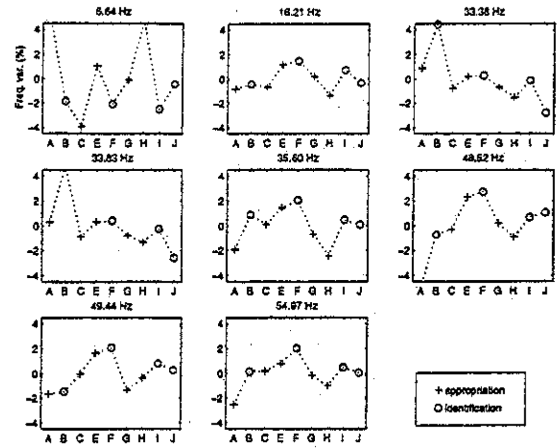
a) Fuselage torsion mode of testbed

Generalized modal parameters when scaled as
UNITY COMPONENT for identifier "gart:112:+Z"

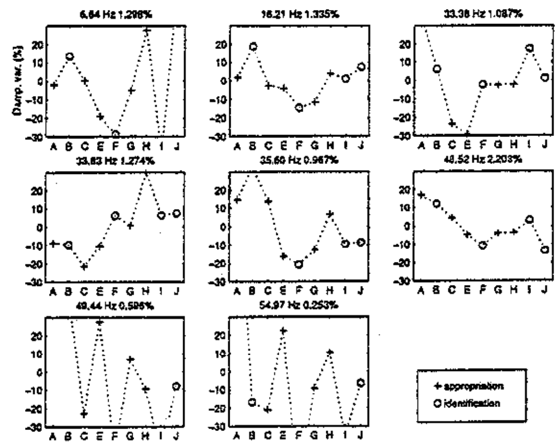
No	mode no	freq Hz	damping (%)	mass kg	damping kg/s	stiffness kg/s2
1	2	16.05	1.47	1.79e+01	5.31e+01	1.82e+05

b) Computation of modal mass

Fig. 12 The modal mass of the fuselage torsion mode



a) Modal frequencies



b) Damping ratios

Fig. 13 Variations in estimated modal frequencies (a) and damping ratios (b) (from ref. 1)

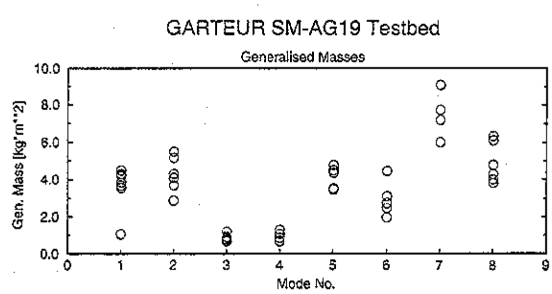


Fig. 14 Comparison of modal mass results (from ref. 2)